Optimizing the Supply-Chain Configuration for New Products

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Abstract

This paper addresses how to configure a new product's supply chain. In this problem, the product's design has already been decided. The central question is to determine what options to select for each stage in the supply chain. For example, there might be alternative vendors to supply a certain raw material, alternative machines or processes to manufacture the assembly, and alternative shipping modes to deliver the completed product to the final customer. Each of these options is characterized by its lead time and direct cost added. Given these various choices along the supply chain, the problem is to select the options that minimize the total supply-chain cost, where the relevant costs are: cost of goods sold, safety stock cost, and pipeline stock cost. The problem is formulated as a two-state dynamic program; details can be found in Willems (1999). This conference proceeding describes an example of the model in order to illustrate the trade-offs that the model captures.

Introduction

Focusing on supply-chain design is one way companies can combat the problems caused by increased competition and shorter product life cycles. Supply-chain design attempts to create the most efficient and effective supply chain for the company's operating environment. This paper addresses how to configure the supply chain for a new product whose design has been decided. The central question is to determine what options to select for each stage in the supply chain. For example, there might be alternative sources or suppliers for a raw material, alternative processes to manufacture a part or perform an assembly, and alternative transportation modes to deliver the completed product to the final customer. We describe each option by its lead time and by its direct cost added at that stage in the supply chain.

Given a set of options for each stage in the supply chain, the problem is to select the options that minimize the total supply-chain cost. We consider three specific costs that are relevant when designing new supply chains: cost of goods sold, safety stock cost, and pipeline stock cost. The configuration problem for the supply chain is to choose one option per stage such that the sum of these costs is minimized. We formulate the problem as a two-state dynamic program. This formulation is an extension of the model in Graves and Willems (1999). In that paper, we develop a single-state dynamic program to minimize the safety stock cost in an existing supply chain.

Willems (1999) presents the details of the supply-chain configuration problem. In this conference proceeding, we restrict our attention to an application of the model. The goal is to demonstrate the approach's applicability and the insights it generates.

Digital Product Example

The product that we studied can be described as a digital capture device. The product converts an analog input into a digital format. Both scanners and digital cameras satisfy this high-level description.

The product consists of three major subassemblies: the imager, the circuit board, and the base assembly. The imager captures the analog input. It is the subassembly that differentiates the product in the marketplace. The imager is created in a four-stage semiconductor process that begins as raw silicate and ends as a completed electronic device, namely a charge coupled device (CCD). The circuit board assembly converts the analog input into a digital output. The production of the circuit board assembly entails the purchase of the components from external vendors and then the in-house assembly and test of the circuit board. The base assembly has two components: the base and an accessory. Both components are purchased from an external vendor.

The assembly process for the digital capture device involves combining the subassemblies into the final product, followed by a functional test. Finally, the product supplies US and export markets.

A graphical depiction of the supply chain is shown below:

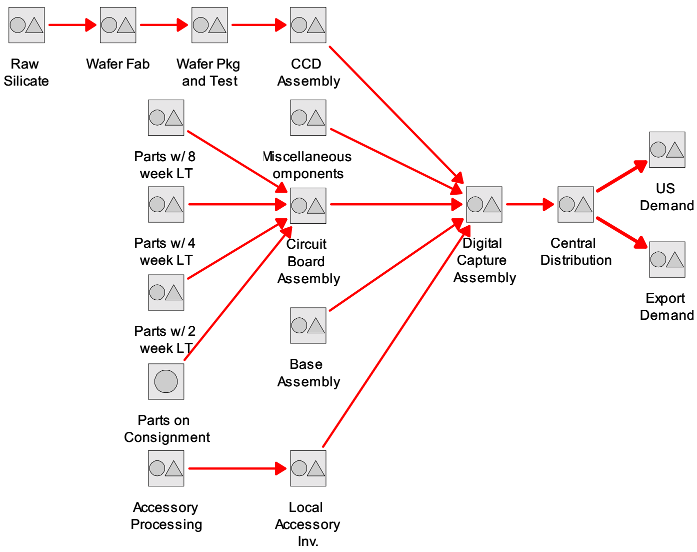

Figure 1: Digital Capture Supply Chain

For the purposes of modeling the supply chain, we have broken the imager subassembly into the four stages at the top of the figure. Raw silicate is fabricated into imagers which are then packaged and tested. An imager is then mounted onto a stand to form the CCD. The components for the circuit board are aggregated into four groups, delineated by their procurement lead times. The base assembly and accessory are depicted in accordance with their previous descriptions. After the digital capture product is assembled, it then goes through central distribution from where it satisfies either US or export demand.

The table below contains the options available when sourcing this supply chain. We identified these options through consultation with the product's materials management group.

Component/Process Description	Option	Production Time	Cost
Raw Silicate	1	60	$5.00
	2	20	$7.50
Wafer Fab	1	30	$800.00
	2	8	$825.00
Wafer Pkg. and Test	1	10	$200.00
	2	5	$225.00
CCD Assembly	1	5	$200.00
	2	2	$250.00
Miscellaneous Components	1	30	$200.00
Parts w/ 8 Week LT	1	40	$105.00
	2	20	$107.62
	3	10	$108.96
	4	0	$110.32
Parts w/ 4 Week LT	1	20	$175.00
	2	10	$177.18
	3	0	$179.39
Parts w/ 2 Week LT	1	10	$200.00
	2	0	$202.50
Parts on Consignment	1	0	$225.00
Circuit Board Assembly	1	20	$225.00
	2	5	$300.00
Base Assembly	1	70	$650.00
	2	30	$665.00
Accessory Processing	1	40	$100.00
Local Accessory Inv.	1	10	$60.00
Digital Capture Assembly	1	6	$420.00
	2	3	$520.00
Central Distribution	1	5	$180.00
US Demand	1	5	$12.00
	2	1	$25.00
Export Demand	1	11	$15.00
	2	2	$40.00

Table 1: Options for Digital Capture Product

The company operates on a five-day work week and there are two hundred fifty days in the year. The annual holding cost rate is thirty percent. The company seeks to minimize the total supply-chain configuration cost incurred over one year.

For each stage, option 1 reflects the option that had been implemented for the existing supply chain. The additional options were judged by the materials management group to reflect {cost added, production lead-time} pairings that were alternatives to the options selected. For instance, there are two options for the procurement of raw silicate. Option 1 has a unit cost of \$5.00 and a procurement time of 60 days; Option 2 is to select a supplier with a shorter procurement time (20 days) but a higher unit cost (\$7.50).

For the circuit board's raw materials, the different options refer to different classes of service that the vendor is willing to provide. The head of materials management for the electronics subassembly estimated that the cost of converting an eight-week lead-time part to a consignment part would equal 5% of the part's eight week selling price. We used this information to estimate the cost of reducing one week of lead-time for each electronic part as 0.625% of the part's selling price.

For the processing stages, the company determined a cost for increasing the capacity at each stage, and thus for reducing the queueing time at that stage. From this we determined the cost per unit required to reduce the lead time at each processing stage. For example, by adding \$25 to the per-unit cost of wafer fab, the lead time was reduced to eight days. A similar analysis was performed for wafer packaging and test, CCD assembly, and the assembly stages.

The two demand stages (US Demand, Export Demand) represent the delivery mode for the product to the company's retail stores. In the case of US demand, the product can either be shipped by ground transportation at a cost of twelve dollars and a transportation time of five days or it can be shipped by air at a cost of twenty five dollars with a one day transportation time. Export demand can be satisfied in a similar manner, albeit with different costs and transportation times. Whereas the faster delivery mode costs more, it will permit the supply chain to require less inventory to provide a high level of service to the demand channel.

The current product is an improved version of an existing product. Therefore, the company used the previous product's sales as well as market forecasts when determining the demand requirements for the supply chain. For US demand, the mean daily demand and standard deviation of demand were estimated as 15 and 9. For Export demand, the estimates were 4 and 2, respectively. At each of the demand stages, the maximum demand over τ days was assumed to be given by $D_j(\tau) = \tau\mu + k\sigma\sqrt{\tau}$ where μ and σ refer to the stage's daily mean and standard deviation of demand. The constant k was chosen to equal 1.645. The supply-chain group felt that this demand bound captured the appropriate level of demand that they wanted to configure their system to meet using safety stock.

Minimizing UMC heuristic

The minimizing unit-manufacturing-cost (UMC) heuristic consists of choosing the least cost option at each stage and then optimizing safety stock placement. This heuristic reflects current practice insofar as the cheapest option at each stage is selected. For the example in Table 1, this corresponds to choosing option 1 for each function.

Given that we specify the option for each stage, then we have set the lead time and direct cost for each stage in the supply chain. Thus, the expected pipeline stock cost (PS) and cost of goods sold (COGS) are determined, once we specify an option for each stage. However, to determine the safety stock cost (SS), we solve the optimization problem in Graves and Willems (1999).

The optimal safety stock policy is to position several decoupling safety stocks across the supply chain. Figure 2 provides a graphical representation of the supply chain's optimal policy.

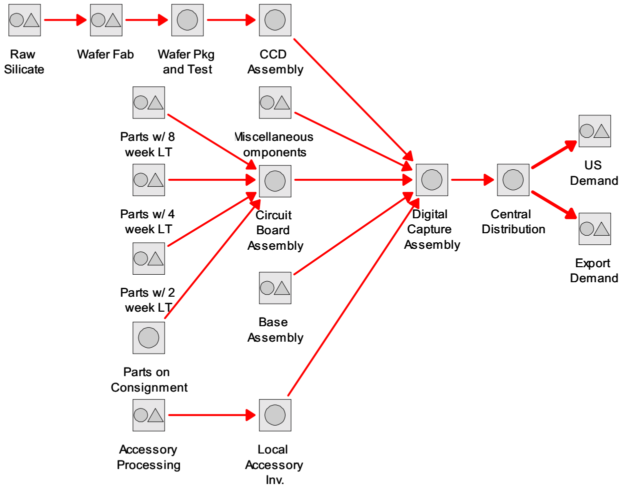

Figure 2: Optimal Safety Stock Placement for Min UMC Heuristic

In the figure, a circle denotes a processing operation and a triangle denotes a safety stock location. Safety stock is held at both of the demand stages. The demand stages are both quoted an inbound service time of 31 days. Given these service times, none of the subassemblies have to hold safety stock in a completed form. In fact, the safety stock policies of the subassemblies can best be described as policies that minimize their individual portions of the supply chain given that they can each quote an outgoing service time of 20 days.

A summary of the configuration's costs are shown below:

SS Cost	$178,386
PS Cost	$979,127
COGS	$17,848,750
Total	$19,006,263

Table 2: Cost Summary for Min UMC Heuristic

The safety stock and pipeline stock costs reflect the company's 30% carrying cost.

Therefore, the initial investment in safety stock and pipeline stock to create the supply chain equals $3,858,376. The expected demand over the course of one year is 4,750 units. Since a completed unit costs either $3,757 or $3,760, depending on the customer region, COGS dominates the total supply-chain configuration cost.

Supply-chain configuration optimization

The supply-chain configuration algorithm considers all of the options in Table 1 and selects the following options at each stage:

Component/Process Description	Option	Production Time	Cost
Raw Silicate	1	60	$ 5.00
Wafer Fab	1	30	$ 800.00
Wafer Pkg. and Test	1	10	$ 200.00
CCD Assembly	1	5	$ 200.00
Miscellaneous Components	1	30	$ 200.00
Parts w/ 8 Week LT	3	10	$ 108.96
Parts w/ 4 Week LT	2	10	$ 177.18
Parts w/ 2 Week LT	1	10	$ 200.00
Parts on Consignment	1	0	$ 225.00
Circuit Board Assembly	1	20	$ 225.00
Base Assembly	2	30	$ 665.00
Accessory Processing	1	40	$ 100.00
Local Accessory Inv.	1	10	$ 60.00
Digital Capture Device Assembly	1	6	$ 420.00
Central Distribution	1	5	$ 180.00
US Demand	2	1	$ 25.00
Export Demand	2	2	$ 40.00

Table 3: Options Selected Using Optimization Algorithm

In this configuration, the company pays a premium for the 8-week and 4-week electronic components so as to reduce their lead-times to 2 weeks. Also, the base assembly's lead-time has been shortened to thirty days and the air shipment of finished goods is preferred over the longer ground shipment option for both US and Export demand.

The optimal stocking policy is represented graphically below:

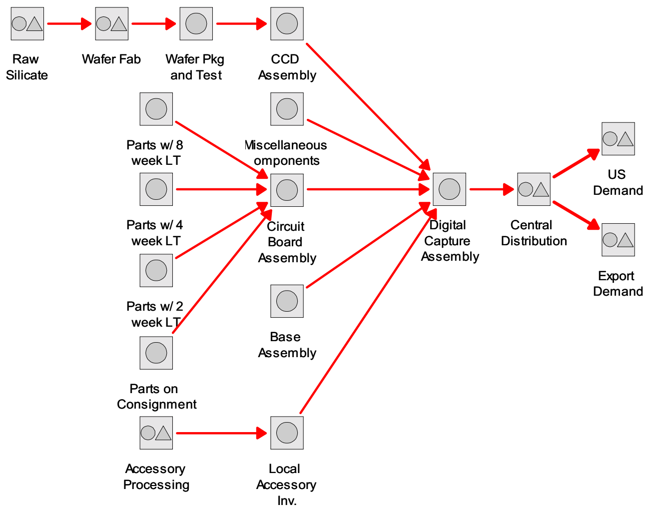

Figure 3: Optimal Safety Stock Placement for Optimization Algorithm

The optimal policy holds a large decoupling inventory at the central distribution center. By holding inventory at the Central Distribution Center, each of the external demand stages can hold significantly less inventory. The primary reason this is optimal is because the higher shipment costs make it less attractive to hold inventory at the external stages. By choosing a two-week procurement time for each of the electronics components (besides the consignment stage) and choosing the base platform option with the shortest lead time, the optimal solution is one where the upstream assemblies are "balanced." That is, each subassembly is configured in the optimal way to quote a service time of 30 to the Digital Capture Assembly.

A summary of the configuration's costs is shown below:

SS Cost	$148,254
PS Cost	$700,097
COGS	$18,022,915
Total	$18,871,266

Table 4: Cost Summary for Optimization Algorithm

The initial investment in safety stock and pipeline stock to create the supply chain equals $2,827,837. This configuration increases the UMC by 1.6% over the min UMC heuristic but decreases the total configuration cost by $135,000. This represents a per unit savings of $28.42.

To help put this cost savings into perspective, the following chart summarizes the costs for the Min UMC configuration when each stage holds safety stock (this situation is depicted in Figure 1):

SS Cost	$237,678
PS Cost	$979,127
COGS	$17,848,750
Total	$19,065,555

Table 5: Cost Summary for Min UMC Heuristic with Service Times Equal to Zero

The Min UMC heuristic with safety stocks at each stage (service times equal to zero) is the most accurate representation of the company's implemented supply chain. The savings generated by optimizing the safety stock levels without changing the supply chain's configuration equals $59,292. The savings generated by jointly optimizing the safety stock levels and the supply chain's configuration total $194,289. Therefore, jointly optimizing both the configuration and the safety stock placement will save three times as much as leaving the configuration unchanged and only optimizing the safety stock placement.

Also, we note that implementing the optimal policy is a relatively easy matter. The difficult step in the supply-chain design process is the identification of the options at each stage that satisfy all of the intangible requirements, such as quality and reliability of supply. However, this step of certifying supply alternatives must be done regardless of which option is eventually chosen. The optimization algorithm just optimally picks among the set of options that are all sufficient to satisfy the product's needs.

Finally, we note that although the overall UMC has not increased by much in the optimal configuration, there is no way the design team would have known to pick this configuration. Table 6 summarizes the costs at the subassembly level for the Min UMC heuristic and the Optimization Algorithm's configuration.

Major Function	Subassembly UMC under Min UMC Heuristic	Subassembly UMC under Optimal Configuration	% difference
Wafer	$1,205	$1,205	0.00%
Base Platform	$810	$825	1.85%
Circuit Board	$930	$936	0.66%
Misc	$200	$200	0.00%
Assembly	$420	$420	0.00%
Distribution	$207	$245	18.36%
Total	$3,772	$3,831	1.54%

Table 6: Comparison of Option Costs for Min UMC and Optimal Configuration

For subassemblies like the base platform, increasing the UMC by $15 is a dramatic increase that would not be authorized without the kind of analysis presented in this section. The same is true of the adoption of premium freight at distribution.

The optimization algorithm also neglected to make some choices that the design team might have considered "obvious" choices. For example, the higher cost raw silicate option was not selected, in that one gets a 40 day reduction in lead time for only $2.50 per unit. Conventional wisdom might have led one to believe that this option would be selected due to the fact that the imager subassembly is an expensive component with a long maximum replenishment time. And with a modest increase in the subassembly's cost, the maximum replenishment time could be significantly shortened. However, the decrease in production time did not offset the subsequent increase in the cost.

References

Graves, S. C. and S. P. Willems, "Optimizing Strategic Safety Stock Placement in Supply Chains," MIT Working Paper, 1999, to appear in *Manufacturing and Service Operations Management*.

Willems, S. P., "Two Papers in Supply-Chain Design: Supply-Chain Configuration and Part Selection in Multigeneration Products," Ph.D. Dissertation, MIT, January 1999.